VisionQuest Biomedical LLC
2501 Yale Blvd. SE, Suite 301
Albuquerque, New Mexico 87106

CAMERA TEST REPORT

Evaluation of two commercial portable retinal cameras

June 16, 2014

Fundus Camera Evaluation

Introduction

Capabilities of fundus cameras have improved dramatically since the 1960s by adding new features to make them more user friendly and to help ensure consistently better quality images. Non-mydriatic imaging, electronic illumination control, automated eye alignment, and high-resolution digital image capture are a few of the major advances. Today there is increased emphasis on portability and low-cost without sacrificing performance, usability and image quality. Due to the significant developments, modern fundus photography has become a standard ophthalmic practice when assessing retinal disease. However each fundus camera has advantages and disadvantages and this study examined two new fundus cameras: the JEDMED Horus Scope and the Volk Pictor Plus, and compared their performance to a standard table-top fundus camera, the Canon CR1 Mark II.

Objective

To evaluate two fundus cameras: the JEDMED Horus Scope and the Volk Pictor Plus, by comparing them to the Canon CR1 Mark II. Technical specifications, usability, and image quality were all considered.

Method

Eight non-diabetic subjects were recruited for this study. All were within the age range of 30-70 years old and five were Latino White, while three were Non-Latino White. There was an even gender split. A two-field imaging protocol was used to acquire optic-disc-centered and macula-centered images of each eye for every subject. The cameras' technical specifications, usability, and image quality were evaluated. For usability, VisionQuest's clinical staff (one experienced user and one naïve user) evaluated several features of each camera, while a certified ophthalmic medical technologist (COMT) evaluated each image for its lesion identification potential and overall quality. A research scientist processed a sample of images to produce histograms for a quantitative image quality evaluation.

Technical Specifications

The resolution for all three devices is given in the Table below. Microaneurysms (MAs), one of the smaller lesions seen on the retina of patients with diabetes, are generally between 43 to 266 microns in diameter. All three devices should be able to resolve the larger MAs, while the Pictor and Horus will be able to resolve only the larger MAs. This statement does not consider the effects of poor quality optics in the devices. The blurring function, or modulation transfer function, of each was not measured. In terms of contrast, a section below is devoted to presenting the contrast measurements for the three cameras. One option that Pictor has provided is contrast enhancement, which was found to improve images significantly.

Pictor Plus

Volk's Pictor Plus is a hand-held fundus camera with interchangeable modules. The four imaging modules include posterior and anterior segment, dermatoscopic, and otoscopic. For this evaluation, only the posterior retinal imaging module was evaluated.

The Pictor Plus provides 5 megapixel image (1536 X 1152 pixels) resolution and incorporates Wi-Fi technology for image transfer to a PC. An easy-access micro SD card slot may be used as a temporary storage unit for images.

LED illumination is available in white or blue. The cobalt blue LED light allows for fluorescent imaging to detect dry eye, cuts, or rashes on the anterior segment of the eye. The white LED is used for fundus imaging. There are three focus modes: Auto, Auto Focus (AF) Assist, and Manual (described further in the "Focus" Section of this report).

Horus Scope

The Horus Scope, a hand-held eye-fundus camera used to record digital photographs and video of the retina, was release by JEDMED in the middle of 2012. Attachments for ear nose and throat, ophthalmology, and audiology are available. For this study only the digital-eye fundus camera (DEC-100) was evaluated.

The camera provides 2 megapixel (1002 X 1002 pixels) resolution images. Videos may be captured and displayed on a 3.5" full color LCD display.

The Horus Scope uses four white LEDs for illumination. A focus wheel found on the handle of the unit allows the user to manually adjust focus.

Canon CR1 Mark II

Canon has long been recognized as a world-leading provider of imaging products and their Canon CR1 Mark II can obtain high-quality and high-resolution retina images very easily. This tabletop device, with its ability to capture 15.1 megapixel images (3002 X 3002 pixels of active imaging area), was used as our gold standard, i.e. to which the test cameras were compared.

Table 1. Technical specifications of each fundus camera.

	JEDMED Horus Scope	Volk Pictor Plus	Canon CR1 Mark II
Resolution	2 Megapixels	5 Megapixels	15.1 Megapixels
Image dimensions	1002 X 1002	1536 X 1152	3002 X 3002
Image Format	JPEG and Video	JPEG and Video	JPEG, DICOM
Field of View	40 Degree	40 Degree	45 Degree
Pixel footprint	40 microns	27 microns	13 microns
Focus Range	-20 to +20D	-20 to +20D	-31D to +33D
Minimum Pupil Size	3.5mm	3mm	3.7mm
Fundus Lighting	White LED	White LED	Incandescent Bulb
Weight	395g (~1 lb)	400g (~1 lb)	21.5kg (47 lb)
Power Supply	Rechargeable NI-MH Battery (3 hours)	Rechargeable NI-MH Battery (3 hours)	AC 100-240
Connectivity	USB	Wi-Fi, USB	USB

Results

Usability: Pictor Plus and Horus Scope

In this section, we will qualitatively compare operability features, such as alignment, of the Pictor Plus and the Horus Scope. Evaluation was provided by two imagers for these tests: one a highly experienced user and the other a newly trained user. The usability features of the CR1 Mark II will be used as the basis for comparison, i.e. the gold standard.

The Canon CR1 Mark II has an internal fixation light to direct the subject's gaze. The user changes the position of the fixation light to prompt the subject to gaze in the desired direction. The number of available alignment targets allow for the capture of all seven ETDRS fields as well as other fields.

The Pictor Plus, an improvement from the original Pictor, has added a fixation target with nine available targets. The red fixation light does have a tendency to come in and out of view as the imager adjusts the camera. However, as long as the patient continues to look in the same general direction while waiting for the light to reappear, it is possible to take consistently aligned photos. The desired alignment was generally not a problem with the population of subjects used in the test.

The Horus Scope camera does not have an internal fixation light, requiring full patient cooperation for any field beyond a macula-centered image. It also becomes more difficult for the user to focus the camera and avoid shadows, as even the most cooperative patients may move their eyes more without a fixation target. Alignment was more difficult and precise positioning of the desired field, for example disc centered or macula centered was problematic.

Comments Usability:

User One (Experienced): The Fixation targets overall assist the imager in directing the patient and therefore obtaining the FOV one wants more efficiently. We feel that it is a requirement in a hand-held camera, or the percent of properly aligned images will suffer.

User Two (Less Experienced): Fixation targets are a huge help when imaging patients. However, in the case of the Horus, if the manufacturer's overall goal is a lightweight device, we see how adding the hardware necessary for fixation may throw the ergonomics off balance. The alignment feature must be assessed further in terms of the intended use criterion. If for example, the expected user has experience in retinal imaging, the fixation light may not be necessary, though always a useful attribute. If the user is a medical technician in a primary care environment and is not accustomed to performing retinal imaging the fixation light become a mandatory requirement.

Figure 1 shows examples of the difficulty in aligning the optic disc along the central meridian. The Horus (lower row) was the only camera where good alignment was inconsistent.

User	Pictor	Horus	Canon
One (Experienced)	Good	poor	Great
Two (Less Experienced)	Good	fair	Great

Fixation

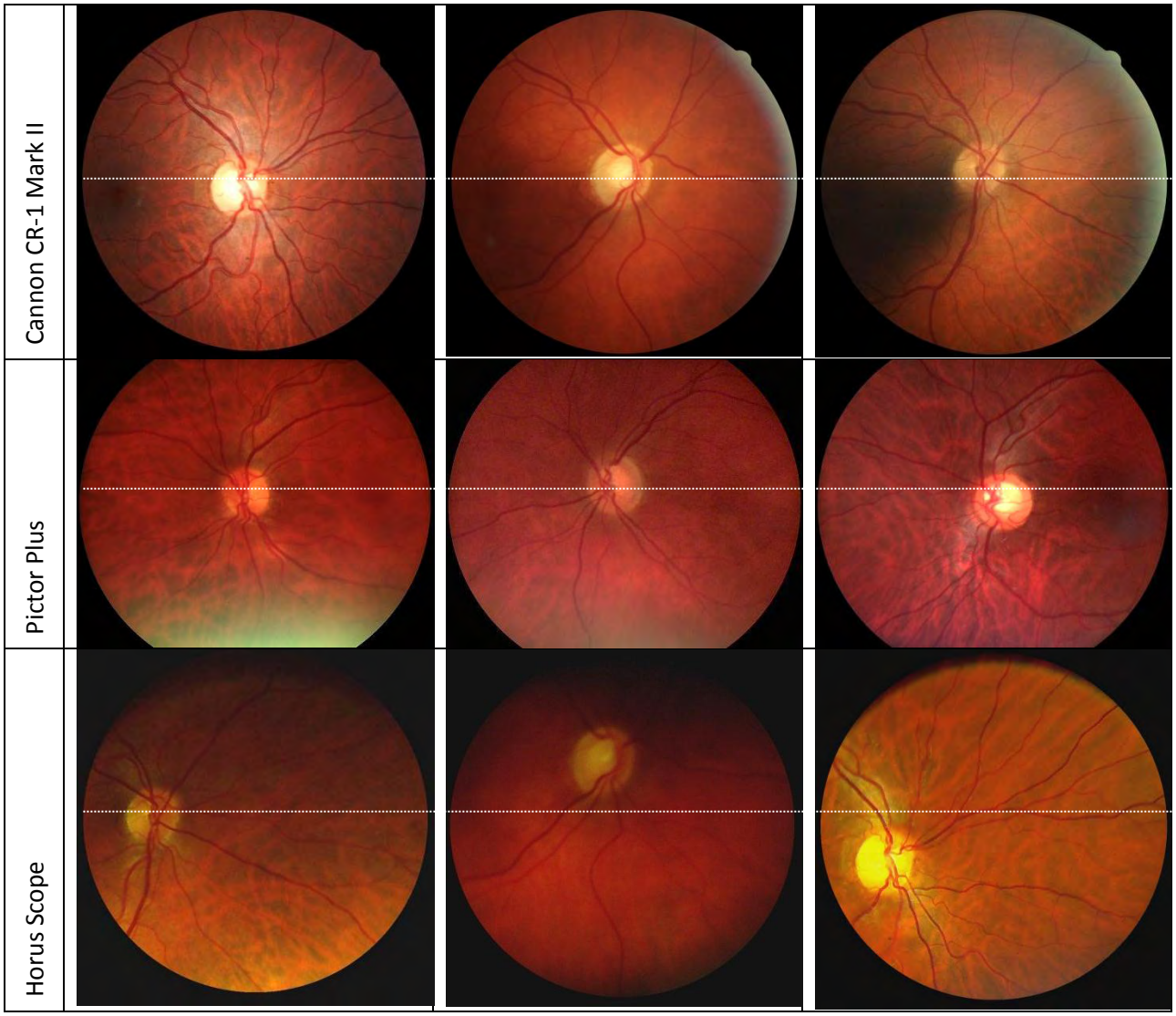


Figure 1. Fixation comparison for the 3 cameras, disc-centered FOV. Top row)Canon CR1-Mark II; Middle row)Pictor Plus; Bottom row)Horus Scope. White horizontal line indicates relative line of sight. In the case of the Horus Scope, consistent fixation to capture disc-centered FOV was not possible on the part of the subjects or the photographer.

Comments Focus:

Focusing the CR1 Mark II is manual, but the camera provides immediate feedback to the user. Split lines and working distance dots, when positioned correctly on the viewing screen, ensure a properly focused image. When dealing with a patient with small/borderline pupils, the working distance dots may be manipulated to move shadows away from the macula. A small pupil button is also available to improve focus.

The Pictor Plus has three focus settings: Manual, Auto, and AF Assist. When using either Auto or AF Assist, a ring of either green or red appears around the retinal view on the handset screen (green = good image quality (poor focus, shadows, etc.), red = bad). The auto focus is very sensitive and often switches from red to green in response to changes that a user may not able to detect visually. In Auto mode, a picture may be taken regardless of whether the ring is green or red. When using the AF Assist setting, the camera will not take a picture unless the green ring remains steady for a few seconds after pressing the shutter button. If a flash of red appears while the camera is attempting to capture the image, refocusing is necessary. Auto mode is preferred over AF Assist for imaging subjects with smaller pupils, as shadows introduced by smaller pupils would prevent image capture in the latter mode.

The Horus Scope requires the user to manually adjust the focus with a wheel located on the front of the handle. The most consistent results are obtained when using the optic disc as the focal point, regardless of its position. Focus may be adversely affected when a subject is wearing contact lenses (as the manual indicated it would be) and especially when they have small/borderline pupils. In these cases, the images are prone to soft focus and increased shadows.

Comments:

User One: The Pictor requires some time and experience to analyze which focus setting works best in which patients and what situation; the Horus is more easily learned with the manual focus adjustment wheel.

User Two: This user described as being frustrated by the Auto focus settings of the Pictor, even when imaging “easy” patients. It is possible to pay too much attention to the changing color rings and ignore what it going on in the actual image. The manual adjustment wheel for the Horus was very easy to access and manipulate, allowing the user to concentrate on the image.

User	Pictor	Horus	Canon
One	Good	Good	Great
Two	Fair	Good	Great

Focus (of patient with smaller pupil)

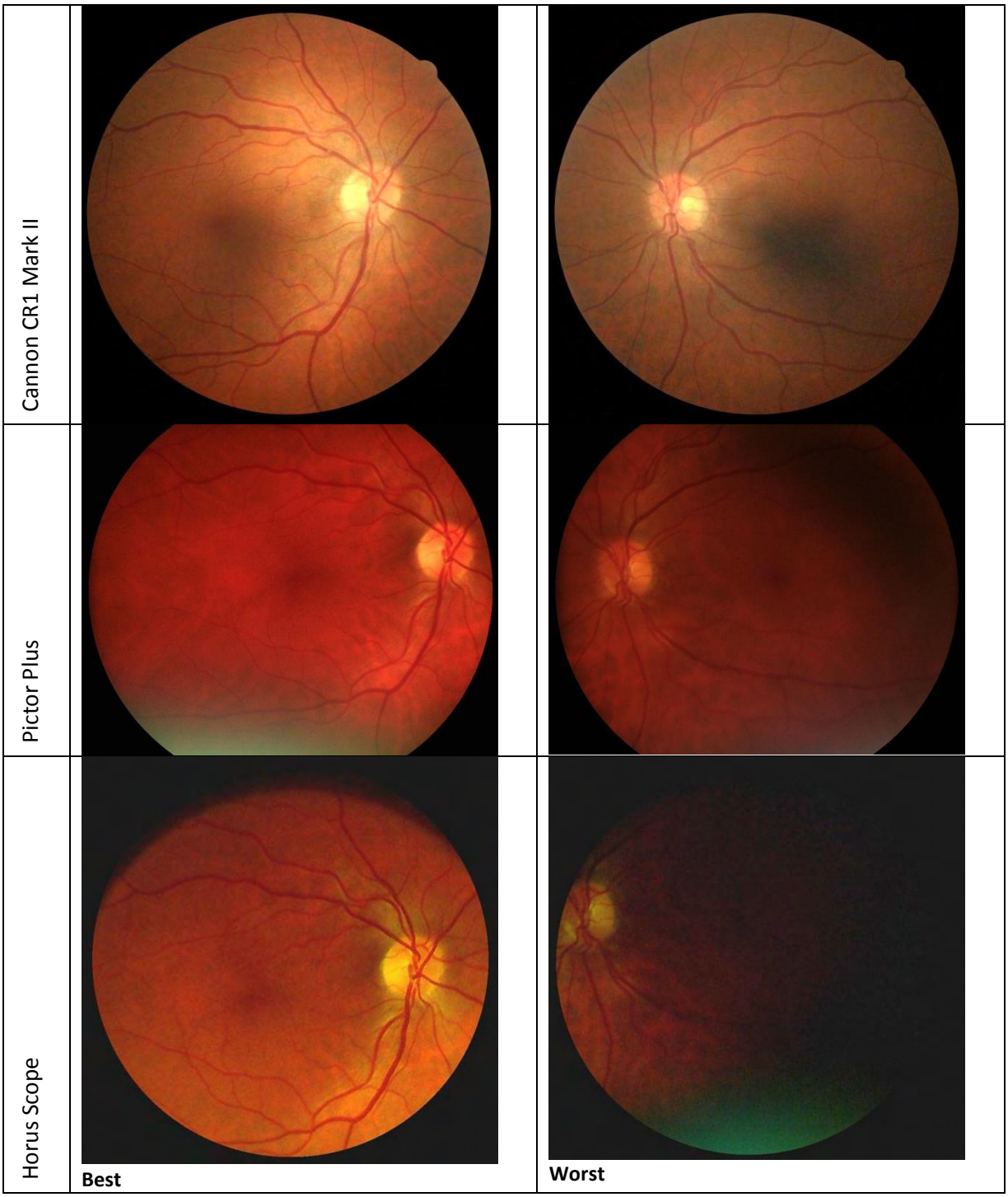


Figure 2. Demonstration for best and worst focus for the 3 cameras. Top row) Canon CR-1 Mark II; Middle row) Pictor Plus; Bottom row) Horus Scope. Left images demonstrate best focus, right images demonstrate worst focus.

Comments Usability:

The Canon CR1 Mark II has an easily adjustable flash. The flash afterimage is acceptable for most non-disease patients. In case of small pupils, it is sometimes necessary, for the sake of image quality, to give the subject a short break between imaging the right and left eye.

The Pictor Plus' flash is not very harsh from a patient perspective. However, it can be difficult to find a single flash setting that is optimal for visualizing the optic disc and macula in a single image. If the macula is clear, the optic disc could be over-illuminated. If fine detail is visible on the optic disc, the macula could be in shadow. Also, many of the images taken by the Pictor Plus have an overly red appearance with reduced contrast. By selecting the Color Correction option, the user may also obtain a processed image with improved contrast, leaving the users to speculate whether this extra processing feature was introduced to compensate for a more patient-friendly flash. This will be discussed further in the Image Quality section below.

The Horus Scope flash was the harshest to the subject of the three, and the afterimage stayed with subjects longer. In at least one case, only one image of an eye at a time would be acquired, meaning that in order to take four images, the user had to switch from right to left to right to left, instead of a normal right right/left left. The flash also had a similar effect to that of the Pictor Plus regarding uneven illumination.

Comments:

User One: The overall flash settings for individual pigmentations require some cropping between different levels for adequate exposure between the disc and the pigment. Bracketing the flash in all cameras is perhaps the best strategy.

User Two: Neither flash performed very well. While the Horus was more difficult for subjects, the Pictor Plus, in many cases, does not produce well-illuminated images unless they have been processed.

Flash:

User	Pictor	Horus	Canon
One	Good	Poor	Good
Two	Fair	Fair	Great

Flash

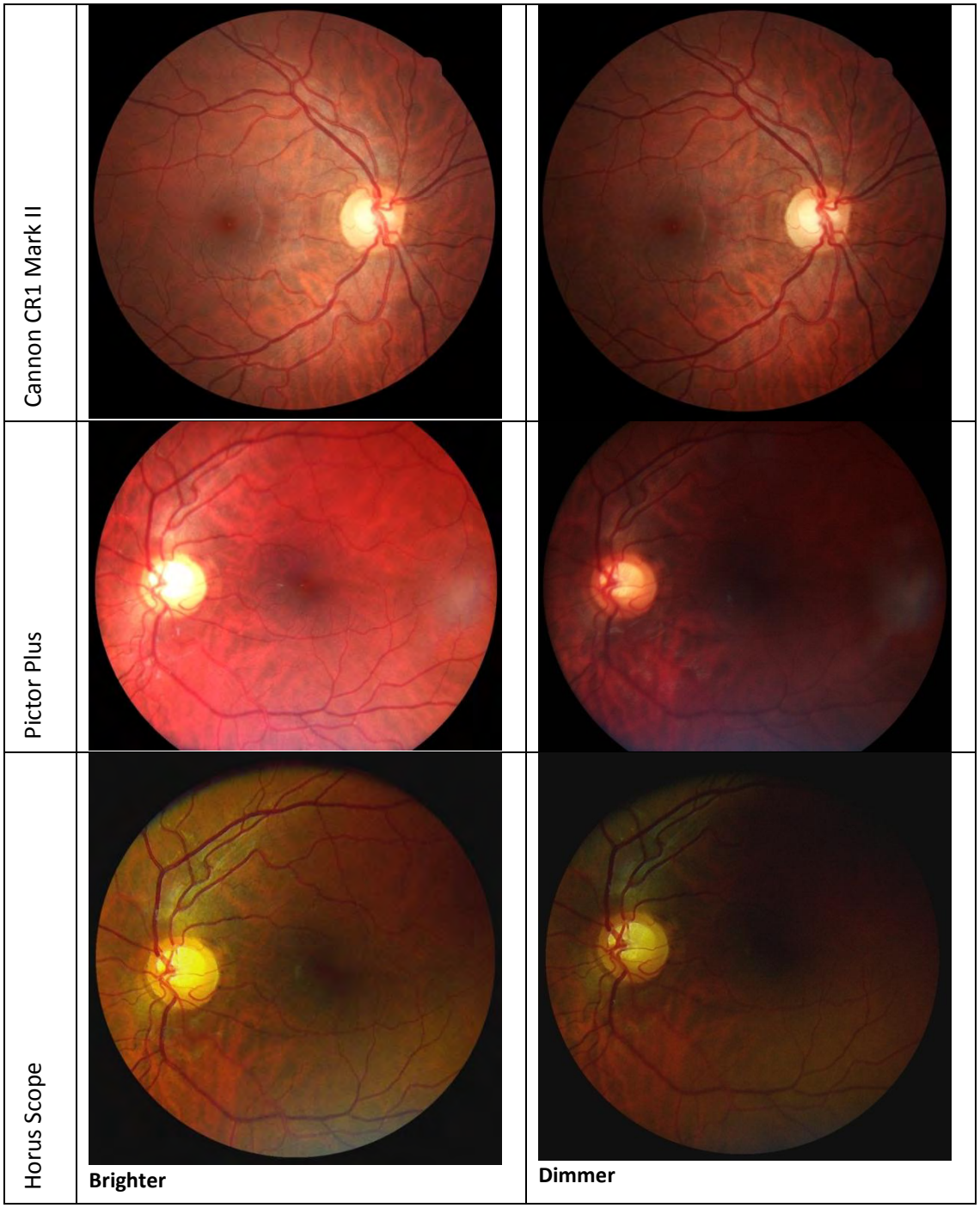


Figure 3. Demonstration for higher and lower flash setting for the 3 cameras. Top row) Canon CR-1 Mark II; Middle row) Pictor Plus; Bottom row) Horus Scope. Left images demonstrate brighter flash setting, right demonstrate dimmer flash setting.

Summary

Pictor Plus

User One: Having used the original Pictor with many patients, this user felt there was significant improvement in the pictures it captured, and the additional feature of the fixation light did help directional movements. The AF mode was useful on a subset of patients who were good fixators with a pupil size of greater than 4.5 to 5 mm. However, this mode was not helpful on more marginal patients with 4.0 mm pupils and other issues (blinkers, eye lashes, contact lenses). The many buttons on the camera did take some time to learn to navigate, but that quickness would come over time and experience.

User Two: While the images are better compared to the original Pictor, the Pictor Plus can be frustrating to use. There were delays in the camera responding to buttons, and it froze occasionally, required restarting. This user felt that the camera was trying to address the many needs of retinal imaging, but the manufacturers may have implemented too many adjustments for their device; thereby, making it more challenging to use.

Horus

User One:
The Horus was lighter weight than the Pictor Plus and the manual comfort of taking the images somewhat easier. It has a well-designed handle and screen and button placement for the imaging task. There is no internal fixation light, which does get difficult when imaging in a dark room. Capturing the image was fairly straightforward. The focus wheel was easy to use and in an appropriate place on the handle. There is no way to create individual patient folders in the camera; therefore the photographer must take careful notes of who is being imaged and in what order. Overall, I feel this camera may be easier to learn and use for the novice imager than the Pictor Plus.

User Two: The Horus Scope is lightweight and easy to handle, with a minimal learning curve for basic operation. It does not have many features, but it was thought that this is a trade-off for overall ease of use. The flash intensity is main concern. If healthy subjects with normal pupils responded to it poorly, it is felt that the higher light intensity would be very uncomfortable on a subject with eye disease or increased light sensitivity.

Image Quality: Pictor Plus, Horus Scope, and CR1 Mark II

To supplement the general statements made in the above section, sample images were selected from subjects to demonstrate the image quality aspects for each camera.

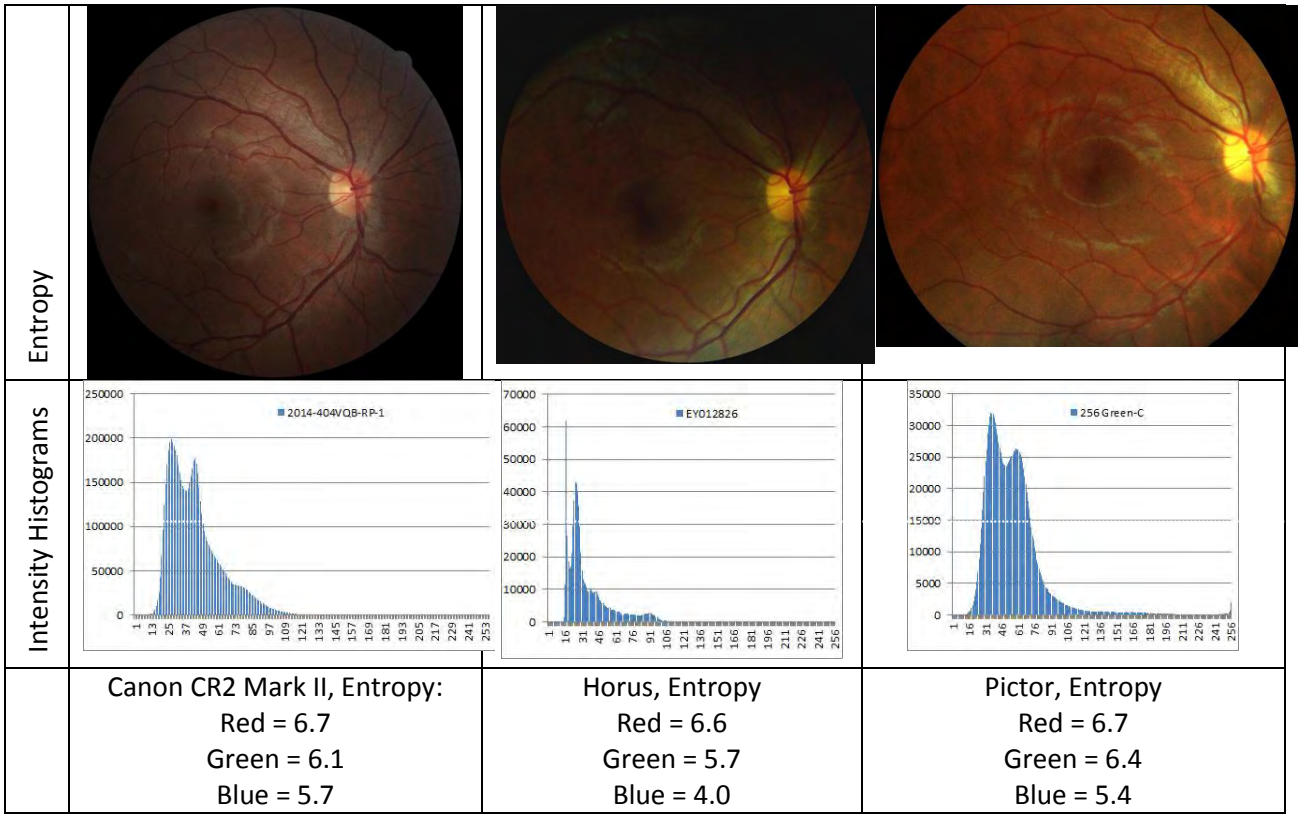
Image Quality Metric

The principal image quality metric used to evaluate the cameras is "entropy." Entropy is a measure of the information content in the image, but is also a strong indicator of the contrast in the image. Entropy is defined as,

$$H = - \Sigma\, p\{x\} * \log_2 p\{x\}$$

Where p{x} is the probability of a given intensity occurring in the image. An image with all the intensity levels represented in the image would have the greatest entropy, so for a 24-bit image (standard in digital cameras) each channel would be represented by 8 bits. The maximum entropy for an 8-bit image would be 8. If only half the intensities are present in an image, it would have an entropy of 4.

Entropy & Image Quality



	Canon CR2 Mark II, Entropy: Red = 6.7 Green = 6.1 Blue = 5.7	Horus, Entropy Red = 6.6 Green = 5.7 Blue = 4.0	Pictor, Entropy Red = 6.7 Green = 6.4 Blue = 5.4

Figure 4. Subject DR. Macula center image from each of the three cameras. Also, the histogram for the green channel and entropy values for each R-G-B channels.

The most salient feature from Figure 4 is the consistently higher entropy for both the Pictor and Canon cameras. In the case of the Pictor, the increased entropy is due to the post processing applied to the image. It is possible that the Pictor applied an analog to digital look-up table that effectively performs histogram stretching.

Entropy & Image Quality

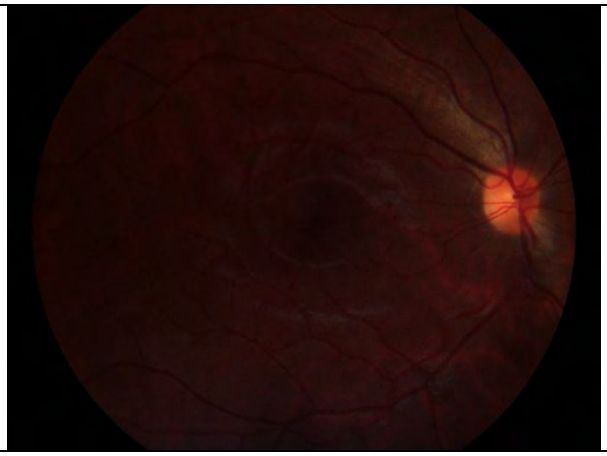
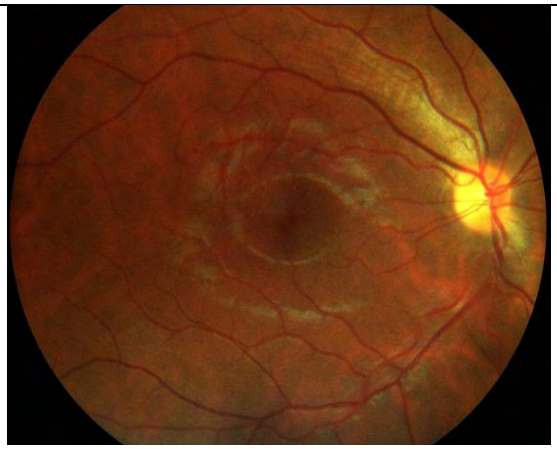
Entropy		
	Pictor Raw Image, Entropy Red = 5.5 Green = 4.3 Blue = 4.2	Pictor Processed Image, Entropy Red = 6.7 Green = 6.4 Blue = 5.4

Figure 5. Subject DR. Pictor initial image (left) and after on-board processing.

Summary

Both qualitative and quantitative assessments showed that the Pictor Plus fundus camera has come close to matching the performance and image quality of the standard desktop cameras. The Horus Scope has many qualities that were felt to give it potential as a low-cost, portable retinal camera. The lower image quality can be improved with some straight forward technical changes. The light source needs to be tuned to the wavelengths that optimize retinal imaging. The detector has insufficient resolution to give images of the quality that users are accustomed to in desktop retinal camera. The nominally 1000 by 1000 pixel format is one-third the size of the Canon camera and two-thirds the size of the Pictor Plus. An external fixation light could be a low-tech solution to the alignment issues identified by the individuals testing the Horus Scope.